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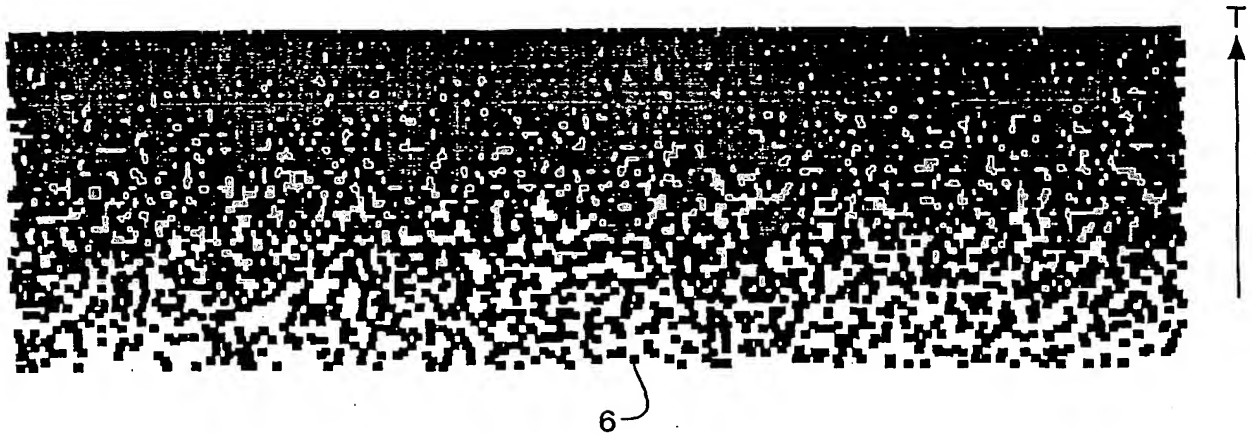
## (54) Method of calibrating a lithographic apparatus

(57) An alignment marker for use in calibration of a lithographic projection apparatus has focus- and dose-sensitive parts, each of which comprises an area having a plurality of dots against a contrasting background forming part of a periodic line structure.

Fig. 5

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## Description

[0001] The present invention relates to calibration of lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate; and
- a projection system for projecting the patterned beam onto a target portion of the substrate.

[0002] The term "patterning means" as here employed should be broadly interpreted as referring to means that can be used to endow an incoming radiation beam with a patterned cross-section, corresponding to a pattern that is to be created in a target portion of the substrate; the term "light valve" can also be used in this context. Generally, the said pattern will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit or other device (see below). Examples of such patterning means include:

- A mask. The concept of a mask is well known in lithography, and it includes mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. Placement of such a mask in the radiation beam causes selective transmission (in the case of a transmissive mask) or reflection (in the case of a reflective mask) of the radiation impinging on the mask, according to the pattern on the mask. In the case of a mask, the support structure will generally be a mask table, which ensures that the mask can be held at a desired position in the incoming radiation beam, and that it can be moved relative to the beam if so desired.
- A programmable mirror array. One example of such a device is a matrix-addressable surface having a viscoelastic control layer and a reflective surface. The basic principle behind such an apparatus is that (for example) addressed areas of the reflective surface reflect incident light as diffracted light, whereas unaddressed areas reflect incident light as undiffracted light. Using an appropriate filter, the said undiffracted light can be filtered out of the reflected beam, leaving only the diffracted light behind; in this manner, the beam becomes patterned according to the addressing pattern of the matrix-addressable surface. An alternative embodiment of a programmable mirror array employs a matrix arrangement of tiny mirrors, each of which can be individually tilted about an axis by applying a suitable localized electric field, or by employing piezoelectric actuation means. Once again, the mirrors are matrix-addressable, such that addressed mirrors will reflect an incoming radiation beam in a different direction to unaddressed mirrors; in this manner, the reflected beam is patterned according to the addressing pattern of the matrix-addressable mirrors. The required matrix addressing can be performed using suitable electronic means. In both of the situations described hereabove, the patterning means can comprise one or more programmable mirror arrays. More information on mirror arrays as here referred to can be gleaned, for example, from United States Patents US 5,296,891 and US 5,523,193, and PCT patent applications WO 98/38597 and WO 98/33096, which are incorporated herein by reference. In the case of a programmable mirror array, the said support structure may be embodied as a frame or table, for example, which may be fixed or movable as required.
- A programmable LCD array. An example of such a construction is given in United States Patent US 5,229,872, which is incorporated herein by reference. As above, the support structure in this case may be embodied as a frame or table, for example, which may be fixed or movable as required.

[0003] For purposes of simplicity, the rest of this text may, at certain locations, specifically direct itself to examples involving a mask and mask table; however, the general principles discussed in such instances should be seen in the broader context of the patterning means as hereabove set forth.

[0004] Lithographic projection apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In such a case, the patterning means may generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target portion (e.g. comprising one or more dies) on a substrate (silicon wafer) that has been coated with a layer of radiation-sensitive material (resist). In general, a single wafer will contain a whole network of adjacent target portions that are successively irradiated via the projection system, one at a time. In current apparatus, employing patterning by a mask on a mask table, a distinction can be made between two different types of machine. In one type of lithographic projection apparatus, each target portion is irradiated by exposing the entire mask pattern onto the target portion in one go; such an apparatus is commonly referred to as a wafer stepper. In an alternative apparatus — commonly referred to as a step-and-scan apparatus — each target portion is irradiated by progressively scanning the mask pattern under the projection beam in a given reference direction (the "scanning" direction) while synchronously scanning the substrate table parallel or anti-parallel to this direction; since, in general, the projection system will have a magnification factor M (generally < 1), the speed V at which the substrate table is scanned will be a factor M times that at which the mask table is scanned. More in-

formation with regard to lithographic devices as here described can be gleaned, for example, from US 6,046,792, incorporated herein by reference.

**[0005]** In a manufacturing process using a lithographic projection apparatus, a pattern (e.g. in a mask) is imaged onto a substrate that is at least partially covered by a layer of radiation-sensitive material (resist). Prior to this imaging step, the substrate may undergo various procedures, such as priming, resist coating and a soft bake. After exposure, the substrate may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. This array of procedures is used as a basis to pattern an individual layer of a device, e.g. an IC. Such a patterned layer may then undergo various processes such as etching, ion-implantation (doping), metallization, oxidation, chemo-mechanical polishing, etc., all intended to finish off an individual layer. If several layers are required, then the whole procedure, or a variant thereof, will have to be repeated for each new layer. Eventually, an array of devices will be present on the substrate (wafer). These devices are then separated from one another by a technique such as dicing or sawing, whence the individual devices can be mounted on a carrier, connected to pins, etc. Further information regarding such processes can be obtained, for example, from the book "Microchip Fabrication: A Practical Guide to Semiconductor Processing", Third Edition, by Peter van Zant, McGraw Hill Publishing Co., 1997, ISBN 0-07-067250-4, incorporated herein by reference.

**[0006]** For the sake of simplicity, the projection system may hereinafter be referred to as the "lens"; however, this term should be broadly interpreted as encompassing various types of projection system, including refractive optics, reflective optics, and catadioptric systems, for example. The radiation system may also include components operating according to any of these design types for directing, shaping or controlling the projection beam of radiation, and such components may also be referred to below, collectively or singularly, as a "lens". Further, the lithographic apparatus may be of a type having two or more substrate tables (and/or two or more mask tables). In such "multiple stage" devices the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposures. Dual stage lithographic apparatus are described, for example, in US 5,969,441 and WO 98/40791, incorporated herein by reference.

**[0007]** As the critical dimension (CD), i.e. the dimension of a feature or features, such as the gate width of a transistor, in which variations will cause undesirable variation in physical properties of the feature, in lithography shrinks, consistency of focus and exposure dose, both across a substrate and between substrates, becomes increasingly important. Traditionally, steppers used energy sensors to monitor the exposure dose by monitoring the output of the illumination system, and image sensors to probe the aerial image. Optimal settings were determined by "send-ahead wafers" i.e. wafers that are exposed, developed and measured in advance of a production run. In the send-ahead wafers, test structures were exposed in a so-called focus-energy matrix (FEM) and the best focus and energy settings were determined from examination of those test structures.

**[0008]** The use of an alignment system to monitor focus has been proposed and an extension of this technique to also measure exposure dose was disclosed in the article "Focus and Exposure Dose Determination using Stepper Alignment" by Peter Dirksen et al, SPIE Vol. 2726/799 (1996). This article describes alignment markers that are modified to form a focus mark and a dose mark. One example of a known alignment mark comprises an array of four phase gratings, two of which have their grating lines aligned in a first direction and the other two having their grating lines perpendicular to the first direction. In the focus mark, the line of the grating is replaced by a chopped structure with a sub-resolution chop linewidth. For example, if the overall grating period is 16μm, the chop linewidth may be in the range of 0.7 to 0.25 μm. In the dose mark, the grating line comprises a transparent part and a part with a transmission of about 0.4.

**[0009]** In the method described by Dirksen, the focus-energy matrix is imaged on a substrate with a radiation-sensitive layer, but the radiation-sensitive layer is not processed. The resulting image is called a "latent image" and is formed by thickness variations as a function of irradiation variations, resulting in phase delay of light diffracted at the mark image. By measuring the position of these modified marks with respect to regular alignment marks, an alignment offset (AO) shows up which is representative of focus and dose errors.

**[0010]** One disadvantage of this method is that the dose calibration must be done in the plane of best focus, because the dose AO is focus-sensitive. Therefore, simultaneous calibration of focus and dose is difficult, if not impossible. Another disadvantage is that AO measurements of latent images are not as representative as AO measurements of processed images. For example, the phase delay properties of a latent image depend upon the resist properties and resist thickness, whereas further downstream in the process (i.e. after developing and stripping of the resist) such dependence is absent. Also, latent images producing easily-measurable AOs can only be formed in resist layers that are thick with respect to typical processed resist layers, and are over-exposed. Consequently, the doses used for the calibration process are not comparable to doses used in actual process steps and so the resulting measurements are not as representative.

**[0011]** The article "Measuring Photolithographic Overlay Accuracy and Critical Dimensions by Correlating Binarized Laplacian of Gaussian Convolutions" by H Keith Nishihara et al, IEEE Transactions on Pattern

Analysis and Machine Intelligence vol. 10 no. 1 January 1988, discloses a method of measuring overlay accuracy and variations in critical dimensions using targets of random patterns of small elements at the minimum feature size of the photolithographic process. The markers are printed and observed with a camera. The camera image is then processed to determine alignment. By adding a grid, changes in the size of the imaged elements cause changes in alignment.

**[0012]** It is an object of the present invention to provide a calibration method that can provide a simultaneous focus and dose calibration more representative of actual processed conditions, whilst using existing alignment tools.

**[0013]** This and other objects are achieved according to the invention in a method of calibrating a lithographic projection apparatus comprising:

- a radiation system for supplying a projection beam of radiation;
- a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
- a substrate table for holding a substrate; and
- a projection system for projecting the patterned beam onto a target portion of the substrate,

**[0014]** the method comprising the step of:

imaging at least one alignment marker provided in said patterning means onto a radiation-sensitive layer on a substrate held by said substrate table, characterized in that:
said alignment marker(s) comprise(s) at least one grating and have a focus-sensitive part and a dose-sensitive part, said focus- and dose-sensitive parts each having a plurality of dots on a contrasting background, said pluralities of dots being arranged, such that variations in focus and dose settings in said imaging step cause shifts in the apparent position of said grating or gratings.

**[0015]** The invention also provides a patterning means, for patterning the projection beam in a lithographic projection apparatus according to a desired pattern, said patterning means being useable to project a pattern comprising at least one alignment marker comprising a focus-sensitive part and a dose-sensitive part, said focus- and dose-sensitive parts each having a plurality of dots on a contrasting background, said pluralities of dots being arranged such that variations in focus- and dose-settings when projecting an image of said marker cause shifts in the apparent position of said grating or gratings.

**[0016]** Preferably, the alignment marker(s) imaged on the radiation-sensitive layer on the substrate is/are then developed and its/their position measured to provide alignment offsets which are representative of focus errors and dose delivered at substrate level. The position of the markers can be measured with a known alignment tool, providing reliable and consistent results. A complete calibration of the focus and dose settings of the apparatus can be obtained by imaging and developing a FEM whereby a plurality of images of the alignment marker(s) are imaged at different dose and focus settings in an array. The invention further provides a second stage to the calibration process whereby dose and focus settings of the apparatus are selected, with the focus setting displaced from a best focus position, and the alignment markers are then imaged at a plurality of different positions on a substrate so as to provide full X-Y calibration of focus and dose for the apparatus, where the X and Y directions are substantially parallel to the plane of the substrate.

**[0017]** With the invention, focus and dose can be calibrated using a plurality of exposures of the alignment marker(s) on a single wafer and at focus and dose settings more applicable to those used in actual processes.

**[0018]** According to a further aspect of the invention there is provided a device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target area of the layer of radiation-sensitive material,

characterized in that the apparatus is first subjected to a focus and dose calibration as described above, and the results of that calibration are subsequently used in determining focus and dose settings employed in the step of projecting.

**[0019]** Although specific reference may be made in this text to the use of the apparatus according to the invention in the manufacture of ICs, it should be explicitly understood that such an apparatus has many other possible applications. For example, it may be employed in the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal display panels, thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "reticle", "wafer" or "die" in this text should be considered as being replaced by the more general terms "mask", "substrate" and "target portion", respectively.

**[0020]** In the present document, the terms "radiation" and "beam" are used to encompass all types of electromagnetic radiation, including ultraviolet radiation (e.g. with a wavelength of 365, 248, 193, 157 or 126 nm) and EUV (extreme ultra-violet radiation, e.g. having a wavelength in the range 5-20nm).

[0021] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which:

Figure 1 depicts a lithographic projection apparatus according to an embodiment of the invention;
Figure 2 shows a modified alignment marker according to a first embodiment of the present invention;
Figure 3 is an enlarged view of a part of the line structure of the alignment marker of Figure 2;
Figure 4 is an enlarged view of another part of the line structure of the alignment marker of Figure 2;
Figure 5 is an enlarged view of a semi-transparent area in the line structure of the alignment marker of Figure 2;
Figure 6 is an enlarged view of a further part of the line structure of the alignment marker of Figure 2;
Figure 7 is an enlarged view of yet a further part of the line structure of the alignment marker of Figure 2;
Figure 8 is an enlarged view of a focus part of the line structure shown in Figures 6 and 7;
Figures 9 and 10 are enlarged views of a semi-transparent part of the line structure of an alignment marker according to a second embodiment of the present invention; and
Figures 11 and 12 are graphs showing experimental results of measurements of alignment offset at various focus offsets and dose levels for focus and dose marks respectively according to the present invention.

[0022] In the Figures, corresponding reference symbols indicate corresponding parts.

Embodiment 1

[0023] Figure 1 schematically depicts a lithographic projection apparatus according to a particular embodiment of the invention. The apparatus comprises:

- a radiation system, Ex, IL, for supplying a projection beam PB of radiation *(e.g.* UV radiation), which in this particular case also comprises a radiation source LA;
- a first object table (mask table) MT provided with a mask holder for holding a mask MA (*e.g.* a reticle), and connected to first positioning means for accurately positioning the mask with respect to item PL;
- a second object table (substrate table) WT provided with a substrate holder for holding a substrate W *(e.g.* a resist-coated silicon wafer), and connected to second positioning means for accurately positioning the substrate with respect to item PL;
- a projection system ("lens") PL *(e.g.* a refractive lens system) for imaging an irradiated portion of the mask MA onto a target portion C (comprising one or more dies) of the substrate W.

[0024] As here depicted, the apparatus is of a transmissive type (*i.e.* has a transmissive mask). However, in general, it may also be of a reflective type, for example (with a reflective mask). Alternatively, the apparatus may employ another kind of patterning means, such as a programmable mirror array of a type as referred to above.

[0025] The source LA (*e.g.* an excimer laser) produces a beam of radiation. This beam is fed into an illumination system (illuminator) IL, either directly or after being passed through conditioning means, such as a beam expander Ex, for example. The illuminator IL comprises adjusting means AM for setting the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in the beam. In addition, it will generally comprise various other components, such as an integrator IN and a condenser CO. In this way, the beam PB impinging on the mask MA has a desired uniformity and intensity distribution in its cross-section.

[0026] It should be noted with regard to Figure 1 that the source LA may be within the housing of the lithographic projection apparatus (as is often the case when the source LA is a mercury lamp, for example), but that it may also be remote from the lithographic projection apparatus, the radiation beam which it produces being led into the apparatus (e.g. with the aid of suitable directing mirrors); this latter scenario is often the case when the source LA is an excimer laser. The current invention and Claims encompass both of these scenarios.

[0027] The beam PB subsequently intercepts the mask MA which is held in a mask holder on a mask table MT. Having traversed the mask MA, the beam PB passes through the lens PL, which focuses the beam PB onto a target portion C of the substrate W. With the aid of the second positioning means (and interferometric measuring means IF), the substrate table WT can be moved accurately, *e.g.* so as to position different target portions C in the path of the beam PB. Similarly, the first positioning means can be used to accurately position the mask MA with respect to the path of the beam PB, *e.g.* after mechanical retrieval of the mask MA from a mask library, or during a scan. In general, movement of the object tables MT, WT will be realized with the aid of a long stroke module (course positioning) and a short stroke module (fine positioning), which are not explicitly depicted in Figure 1. However, in the case of a wafer stepper (as opposed to a step-and-scan apparatus) the mask table MT may just be connected to a short stroke actuator, or may be fixed.

[0028] The depicted apparatus can be used in two different modes:

1. In step mode, the mask table MT is kept essentially stationary, and an entire mask image is projected in one go (*i.e.* a single "flash") onto a target

portion C. The substrate table WT is then shifted in the x and/or y directions so that a different target portion C can be irradiated by the beam PB;

2. In scan mode, essentially the same scenario applies, except that a given target portion C is not exposed in a single "flash". Instead, the mask table MT is movable in a given direction (the so-called "scan direction", *e.g.* the x direction) with a speed *v*, so that the projection beam PB is caused to scan over a mask image; concurrently, the substrate table WT is simultaneously moved in the same or opposite direction at a speed $V = Mv$, in which $M$ is the magnification of the lens PL (typically, $M = 1/4$ or 1/5). In this manner, a relatively large target portion C can be exposed, without having to compromise on resolution.

**[0029]** Figure 2 shows an alignment mark 1 which is provided on a mask, *e.g.* formed of chromium light blocking areas on a vitreous substrate, and used for calibration according to the calibration method of the present invention. As can be seen in Figure 2, the alignment mark 1 comprises four quadrants 11 to 14 each of which comprises a grating structure. Two of the quadrants 11, 12 have their grating lines aligned in a first direction, horizontal in the Figure, and the other two quadrants 13, 14 have their grating lines arranged in the perpendicular direction, vertical in the Figure. The grating lines in quadrants 11 and 12 are modified from the standard form to enable measurement of dose variations, whilst those in quadrants 13 and 14 are modified to measure focus variations. It should be noted that the quadrants modified for focus and dose calibration need not be horizontally adjacent as shown, but may also be vertically or diagonally adjacent. Also, the focus-sensitive quadrants may be provided in a different alignment marker than the dose-sensitive quadrants. Further, it is not always necessary to modify an entire quadrant to be focus- or dose-sensitive; part of the quadrant may have the standard line structure.

**[0030]** As shown in Figure 3, which is an enlarged view of part of the line structure of quadrant 11, the grating period P comprises a structure of three lines: a chrome area 2, a clear area 3 and a dose-sensitive area 4. As shown in Figure 4, the line structure of the grating of quadrant 12 contains the same elements, but with the order changed by interchanging the clear area 3 and dose-sensitive area 4. The dose-sensitive area 4 comprises an area of variable transmissivity, with the transmissivity T increasing monotonically from the chrome area 2 towards the clear area 3. The required transmissivity can be obtained, for example, by a pseudo-random pattern of clear and transparent areas or dots of a size smaller than can be resolved by the projection system and appropriately distributed. Such an arrangement is shown in Figure 5 in which the black dots represent clear dots in a chromium layer on the mask. Where the wavelength of the projection beam is 248nm and the numerical aperture of the projection system is 0.6, the size of the dots may be, for example, such as would image as dots of about 0.13μm diameter on the wafer.

**[0031]** When the quadrants 11 and 12 are imaged on a wafer, the dose received at the wafer will vary across the region of the image of the dose-sensitive part 4. At some point across the width of that image, the dose delivered will cross the resist threshold so that the resist will be effectively exposed on the higher transmissivity side of that line and not exposed on the lower transmissivity side. The position of the dividing line will depend upon the effective dose reaching the wafer. When the wafer is processed and developed, the line thickness of the developed alignment marker will depend upon the position of the line between exposed and non-exposed parts of the image of the dose-sensitive region and this will result in an apparent shift of position of the alignment marker when its position is measured. Also, because the clear dots are of sub-resolution size, the position of the dividing line will be substantially independent of focus. This alleviates the disadvantage of the prior art dose AO being focus-sensitive. By printing a plurality of images of the alignment marker at different energy settings and measuring the resultant alignment offsets, the apparatus can be calibrated by correlating the actual dose delivered at wafer level to the energy settings of the apparatus.

**[0032]** The line structure of quadrants 13 and 14 of alignment mark 1 again comprises a repeating period of three regions, as shown in Figure 6 and Figure 7. The line structure of quadrant 13 comprises a chrome area 2, a clear area 3 and a focus-sensitive area 5. The line structure of quadrant 14 is the same, but with the clear area 3 and focus-sensitive part 5 interchanged. The structure of the focus-sensitive part is shown in more detail in Figure 8. As can there be seen, the focus-sensitive area 5 consists of a hexagonal array of chrome dots 7 within an otherwise clear area. The pitch D between dots may, for example, be 1.8μm, and the dot diameter d may, for example, be 0.6μm. The FEM imaging, characteristic for the first stage, and the focus- and dose-marker imaging at different X-Y positions, characteristic for the second stage, can also be executed in one single run, i.e. without developing the wafer after the FEM exposure. In this way the focus and dose calibration of alignment offsets and the full X-Y focus and dose calibration can be done in one single step.

**[0033]** When the image of the focus-sensitive area 5 on the wafer is correctly focused, the chromium dots 7 will be imaged in the developed resist and will result in a darker area adjacent the printed dark area 2 than would be the case for poorly focused dots, so that there will be an apparent shift in the measured position of the developed alignment marker. As the image of the focus-sensitive area 5 moves out of focus the effective diameter of the imaged spots will reduce. Thus the centre of gravity of the imaged mask will shift so that an alignment offset is observed. It should be noted that the density of

the focus-sensitive part must be kept below the threshold at which iso-focal behaviour occurs. Above that threshold and above a certain energy, no focus-sensitive behaviour is observed. The density and energy at which iso-focal behavior is observed can be calculated or determined experimentally.

**[0034]** To calibrate the apparatus, a two-stage process is carried out. In the first stage the dependence of alignment offset of an alignment marker according to the invention on focus and dose is measured experimentally by printing an FEM on the wafer. The FEM comprises a plurality of images of the alignment marker printed with different focus and dose settings of the apparatus. The wafer is then developed and the alignment offset for each of the images of the alignment marker 1 is measured. From the measured dependence of the alignment offsets on focus and dose, two sets of curves, one giving alignment offset as a function of focus, parameterized by dose, and the other giving alignment offset as a function of dose, parameterized by focus, can be generated. The two sets of curves give complete information on the relationship between alignment offset and focus and dose.

**[0035]** In the second stage specific focus and dose values are chosen. The dose is chosen to be typical for the process window of interest and the focus is chosen to be somewhat away from the best focal position; typically the curves for alignment offset as a function of focus take the form of parabolas and the selected focal position is somewhat away from the peak of those parabolas. With the selected dose and focus values, the alignment marker 1 is imaged on a test substrate at a plurality of X-Y positions. The wafer is then developed and complete information on the dependence of alignment offset and dose and focus at different X-Y positions can be determined.

Embodiment 2

**[0036]** In a second embodiment, which is otherwise the same as the first embodiment, the focus- and dose-sensitive parts of the alignment marker are replaced by random patterns of dots and holes as illustrated in Figures 9 and 10 to result in an alignment marker which is both focus- and dose-sensitive. Specifically, two of the quadrants have a focus- and dose-sensitive part 21, as shown in Figure 9, which comprises a random array of chromium dots 22 on a clear background. The other two quadrants have a focus- and dose-sensitive part 23 which comprises a random array of holes 24 in a chromium background. Note that whilst the pattern shown in Figure 10 is the exact negative of the pattern shown in Figure 9 this need not in practice be the case and the pattern of holes may be entirely different than the pattern of dots. In defining the random pattern of dots or holes, minimum and maximum dot and hole sizes may be specified as well as a minimum separation.

Experimental Results

**[0037]** Experimental results deriving from the printing and measurement of a focus energy matrix on a reticle are shown in Figures 11 and 12. In the focus energy matrix, the alignment marker of the present invention was exposed at 16 focus steps from -1.5 to +1.5μm, relative to a nominal zero, and at nine nominal energy levels from 40 to 150mJ/cm$^2$. Figure 11 shows the curves relating alignment offset to focus for different energy levels for the focus marker whereas Figure 12 shows the curves for alignment offset relative to focus for different energy levels for the dose marker. The clearly different focus and dose response shows that the focus and dose can be separately determined.

**[0038]** Whilst specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention. For example, the focus- and dose-sensitive parts may be incorporated in other types of alignment marker, for example checker-board markers or box-in-box markers for use with a KLA overlay tool.

**Claims**

1. A method of calibrating a lithographic projection apparatus comprising:

   - a radiation system for providing a projection beam of radiation;
   - a support structure for supporting patterning means, the patterning means serving to pattern the projection beam according to a desired pattern;
   - a substrate table for holding a substrate;
   - a projection system for imaging the patterned beam onto a target portion of the substrate,

   the method comprising the step of:

   imaging at least one alignment marker provided in said patterning means onto a radiation-sensitive layer on a substrate held by said substrate table, **characterized in that:**
   said alignment marker(s) comprise(s) at least one grating and have a focus-sensitive part and a dose-sensitive part, said focus- and dose-sensitive parts each having a plurality of dots on a contrasting background, said pluralities of dots being arranged, such that variations in focus and dose settings in said imaging step cause shifts in the apparent position of said grating or gratings.

2. A method according to claim 1 wherein said grating comprises a plurality of solid lines and said focus

and dose sensitive parts are arranged adjacent ones of said solid lines whereby said variations in focus and dose settings change the apparent widths of said ones of said solid lines.

3. A method according to claim 1 or 2, wherein said focus sensitive part comprises a hexagonal array of dots.

4. A method according to claim 3 wherein said focus sensitive part comprises a repeating structure of lines, said lines comprising, in each period of said repeating structure, a substantially opaque line, a substantially transparent line and a line having said hexagonal array.

5. A method according to any one of the preceding claims wherein said dose sensitive part comprises a plurality of sub-resolution dots having a size such as to image at a size smaller than the effective resolution of said apparatus and arranged in an area so as to have a density increasing in a first direction across said area.

6. A method according to claim 5 wherein said dose sensitive part comprises a repeating structure of lines, said lines comprising, in each period of said repeating structure, a substantially opaque line, a substantially transparent line and a line having said plurality of sub-resolution dots.

7. A method according to claim 4 or 6 wherein said alignment mark comprises first and second dose sensitive parts and/or first and second focus sensitive parts, the order of lines in said repeating structures being different in said second dose and/or focus sensitive parts than in said first dose and/or focus sensitive parts.

8. A method according to any one of the preceding claims wherein in said step of imaging, a plurality of images of said alignment marker(s) are imaged at different dose and focus settings of the apparatus, and further comprising the steps of:

measuring the positions of the developed images of said alignment markers; and
determining from the measured positions the focus and dose characteristics of said apparatus.

9. A method according to claim 2 further comprising the steps of:

selecting a dose setting and a focus setting of the apparatus, said focus setting being displaced from a best focus position;
imaging said alignment marker(s) at a plurality of different positions on a radiation-sensitive layer of a substrate, using said selected dose and focus settings;
measuring the positions of said images of said alignment markers; and
determining from the measured positions any non-conformities with position in the focus and dose characteristics of said apparatus.

10. A method according to claim 9 further comprising the steps of:

determining any systematic components of said non-conformities; and
adjusting settings and/or parameters of said apparatus to reduce or compensate for said systematic components.

11. A method according to claim 9 or 10 wherein the steps of selecting a dose setting and a focus setting and imaging said alignment marker(s) at a plurality of positions are performed concurrently with the step of imaging a plurality of images of said alignment marker(s) at different dose settings.

12. A method according to claim 9, 10 or 11 further comprising the step of:

developing said images before the step(s) of measuring positions.

13. A method according to any one of claims 8 to 12 wherein in said step or steps of measuring, the position of said images is measured using an alignment system that images selected diffraction orders of light reflected by said images on a reference grating.

14. A patterning means, for patterning the projection beam in a lithographic projection apparatus according to a desired pattern, said patterning means comprising at least one alignment marker comprising a focus-sensitive part and a dose-sensitive part, said focus- and dose-sensitive parts each having a plurality of dots on a contrasting background, said pluralities of dots being arranged such that variations in focus- and dose-settings when projecting an image of said marker cause shifts in the apparent position of said grating or gratings.

15. A patterning means according to claim 14 wherein said focus sensitive part comprises a hexagonal array of dots.

16. A patterning means according to claim 15 wherein said focus sensitive part comprises a repeating structure of lines, said lines comprising, in each period of said repeating structure, a substantially

opaque line, a substantially transparent line and a line having said hexagonal array.

17. A patterning means according to claim 14, 15 or 16 wherein said dose sensitive part comprises a plurality of sub-resolution dots having a size such as to image at a size smaller than the effective resolution of said lithographic projection apparatus and arranged in an area so as to have a density increasing in a first direction across said area.

18. A patterning means according to claim 16 wherein said dose sensitive part comprises a repeating structure of lines, said lines comprising, in each period of said repeating structure, a substantially opaque line, a substantially transparent line and a line having said plurality of sub-resolution dots.

19. A patterning means according to claim 16 or 18 wherein said alignment mark comprises first and second dose sensitive parts and/or first and second focus sensitive parts, the order of lines in said repeating structures being different in said second dose and/or focus sensitive parts than in said first dose and/or focus sensitive parts.

20. A patterning means according to any one of claims 14 to 19, wherein the patterning means comprise a mask table for holding a mask.

21. A lithographic projection apparatus comprising:

- a radiation system for providing a projection beam of radiation;
- patterning means, for patterning the projection beam according to a desired pattern;
- a substrate table for holding a substrate;
- a projection system for imaging the patterned beam onto a target portion of the substrate,

**characterized in that:**

said patterning means comprises at least one alignment marker comprising at least one grating and has a focus-sensitive part and a dose-sensitive part, said focus- and dose-sensitive parts each having a plurality of dots on a contrasting background, said pluralities of dots being arranged such that variations in focus and dose settings in said imaging step cause shifts in the apparent position of said grating or gratings.

22. A device manufacturing method comprising the steps of:

- providing a substrate that is at least partially covered by a layer of radiation-sensitive material;
- providing a projection beam of radiation using a radiation system;
- using patterning means to endow the projection beam with a pattern in its cross-section;
- projecting the patterned beam of radiation onto a target area of the layer of radiation-sensitive material,

**characterized in that** prior to said step of providing a substrate, said apparatus is calibrated according to the method of any one of claims 1 to 13.

23. A device manufactured according to the method of claim 22.

Fig. 1

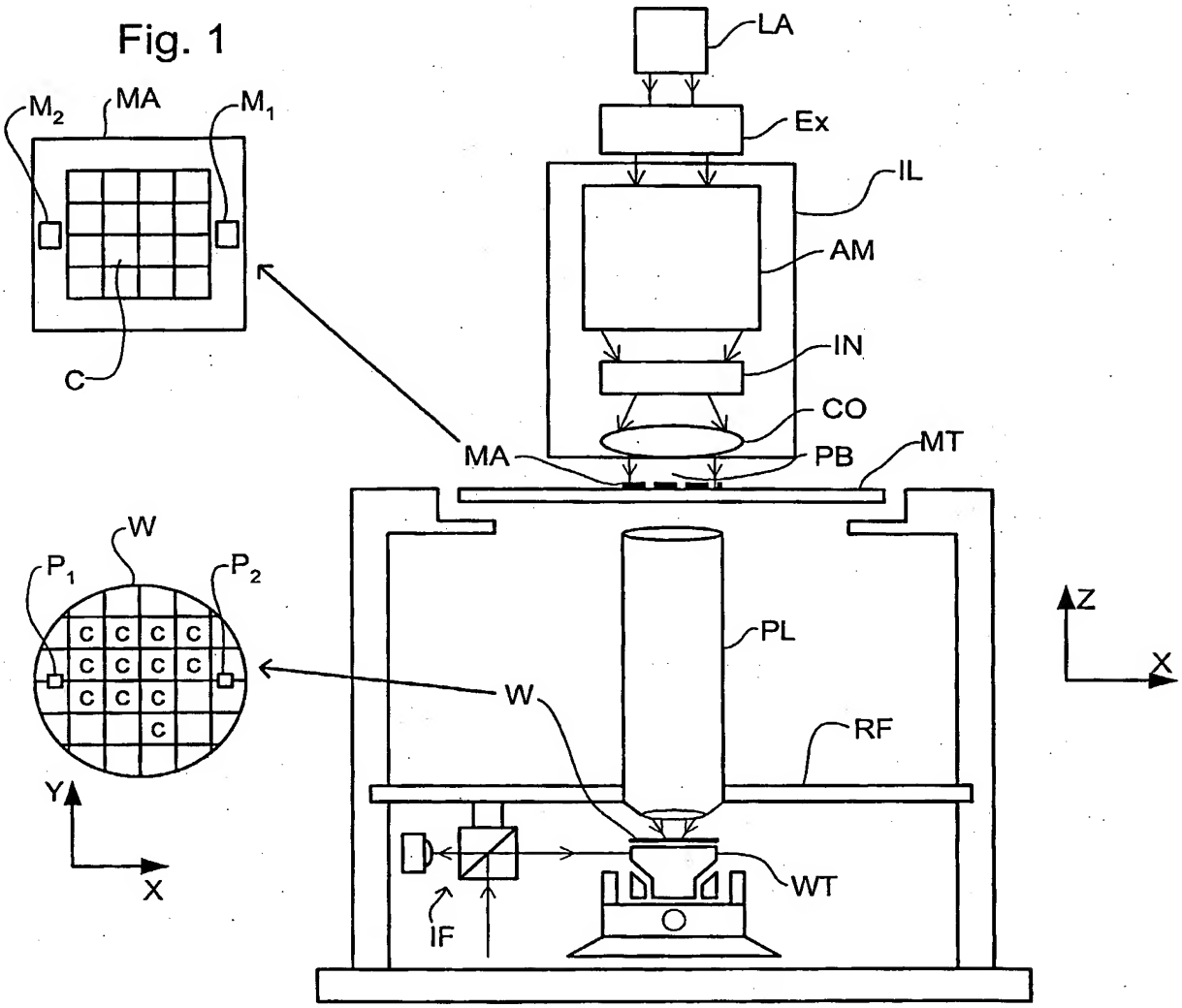

Fig. 2

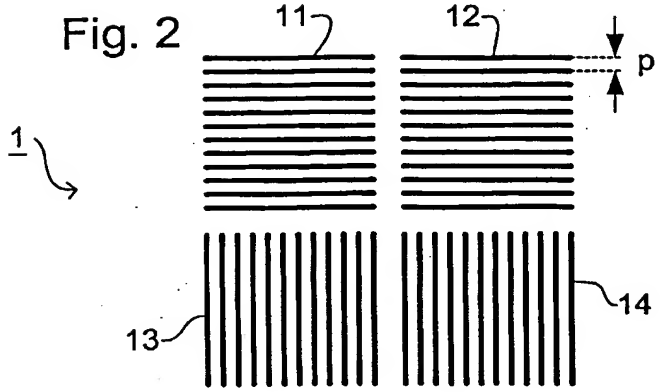


Fig. 3

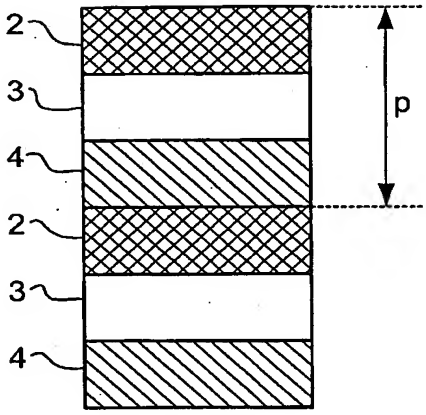


Fig. 4

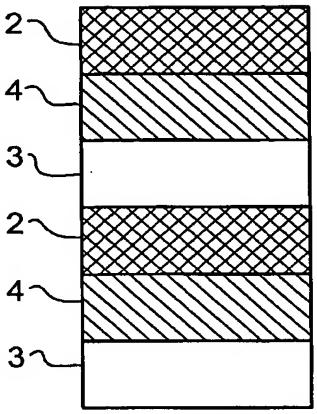


Fig. 5

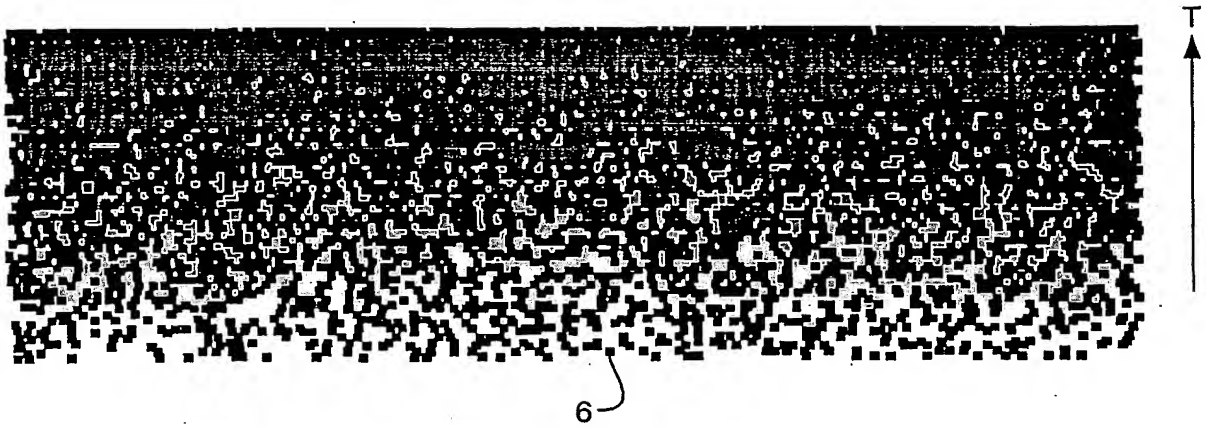


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Fig. 6

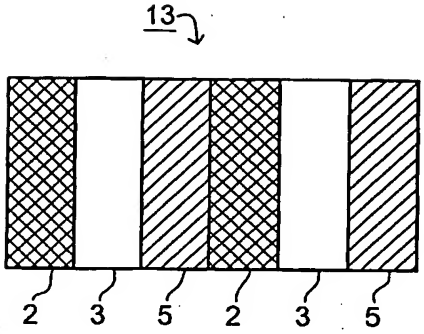


Fig.7

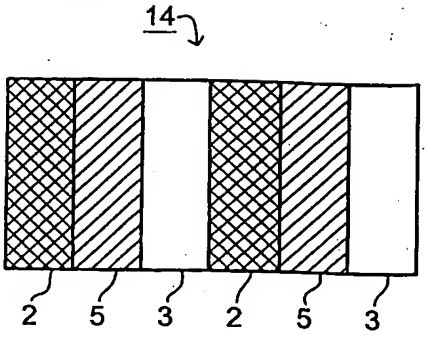


Fig. 8

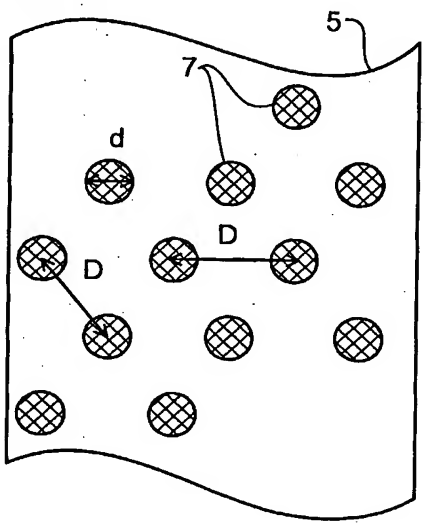


Fig. 9

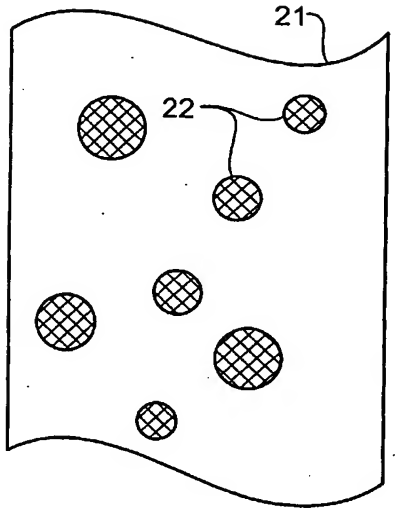


Fig. 10

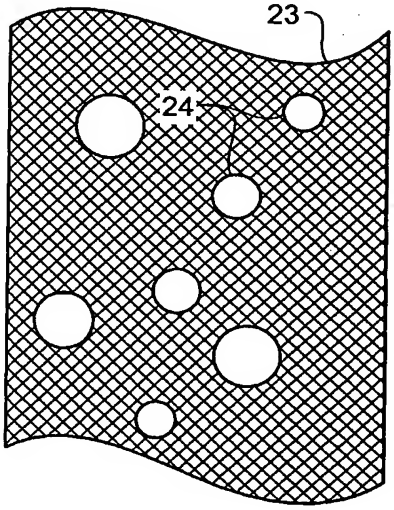


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Fig. 11

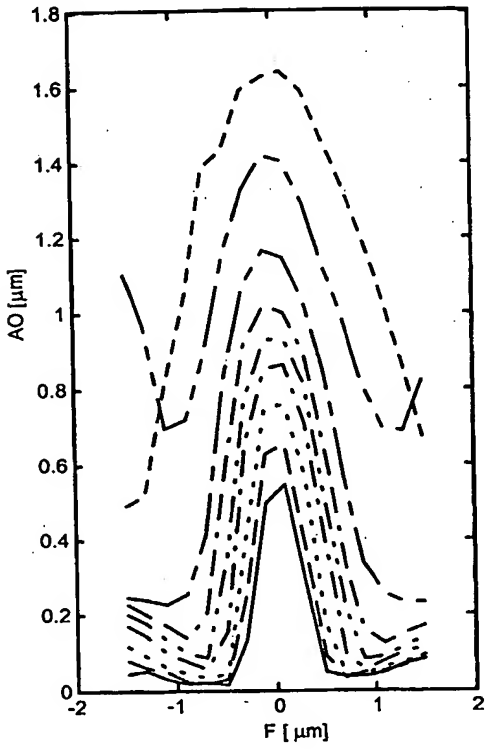
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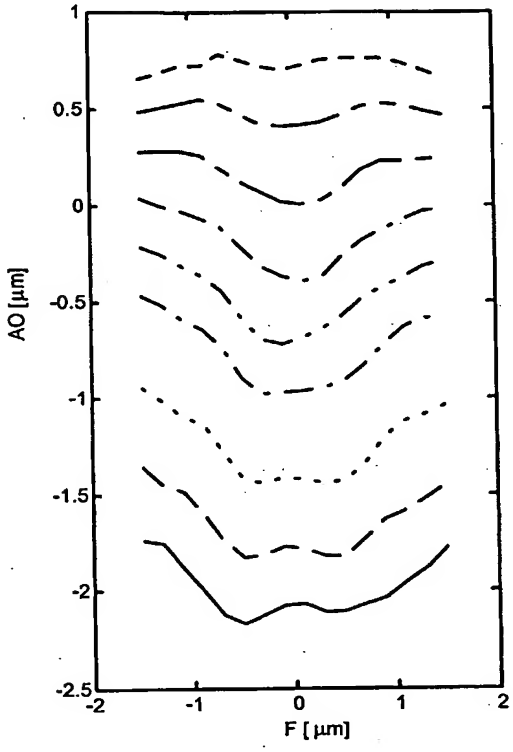
Fig. 12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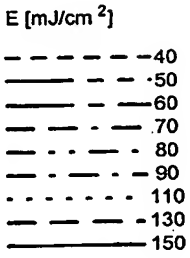
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# EUROPEAN SEARCH REPORT

Application Number
EP 02 25 3177

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The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 3 July 2002 | Heryet, C |

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Application Number
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| Place of search | Date of completion of the search | Examiner |
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D : document cited in the application
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